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Parasites of Some Penaeid Shrimps with Emphasis on Reared Hosts

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Abstract

Information is presented about parasites and commensals of penaeid shrimps, allowing those who rear shrimps and those who are interested in associated organisms of shrimp to have a better knowledge of the organisms that are or may be associated with brown, white, and pink shrimps. It covers common and rare organisms and diseases, primarily in the northern Gulf of Mexico, listing several previously unreported species including an undescribed gregarine, a larval nematode (*Spirocarnallanus pereirai*), a commensal nematode (*Leptolaimus* sp.), a leech (*Myzobdella lugubris*), a blue-green alga (*Schizothrix calcicola*), a hydroid (*Obelia bicuspidata*), and others. A possible relationship between the peritrich ciliate, *Zoothamnium* sp., and predilection to mortality following stress is discussed. Comparative data are given for organisms from brown and white shrimp from different ponds and the natural environment between 1969 and 1972 at Grand Terre, Louisiana. Also reported are organisms observed in or on shrimp from floating cages in Alabama and ponds in Florida and Texas, as well as wild stock from Mississippi and Georgia.

Introduction

Since parasites and diseases of shrimps threaten the productivity of rearing facilities, this study will help those concerned with rearing shrimp. It enumerates the common, lesser known, and previously unreported organisms associated with populations of penaeid shrimps reared in ponds and cages as well as those collected from natural habitats. Emphasis is placed on the brown shrimp, *Penaeus aztecus* Ives, and the white shrimp, *P. setiferus* (L.), also called *P. fluviatilis* Say (for discussions on nomenclature see articles by Gunter, 1962; Holthuis, 1962; Perez Farfante, 1969), from the northern Gulf of Mexico. The pink shrimp, *P. duorarum* Burkenroad, is also included.

While rearing shrimps has progressed considerably during the past few years, as witnessed from reports of the FAO World Scientific Conference on the Biology and Culture of Shrimps and Prawns, research concerning parasites and diseases of shrimps remains deficient. Many parasites of commercial penaeids were described or reviewed by Kruse (1959) and Hutton et al. (1959), and their presence in cultural pink shrimp in southern Florida was reported by Villella et al. (1970). Sindermann and Rosenfield (1967), Sprague (1970), and Sprague and Couch (1971) discuss some of the parasites. Additional papers including citations, descriptions, or discussions on individual parasites or diseases will be mentioned later.

Brown and white shrimps

Brown, white, and pink shrimps compose a large fishery in the Gulf of Mexico. While the brown shrimp constitutes over half the catch, the white shrimp provides slightly over a quarter. Pink shrimp are caught primarily off the coasts of Florida and the Yucatan Peninsula, whereas the white and brown shrimps are taken primarily in the northern Gulf. Although the larvae of all three species develop into juveniles in low salinity estuaries, the adult pink shrimp are less often found in low salinity habitats than the other two.

Brown shrimp of commercial size typically burrow in muddy, sandy bottoms at a depth between 18 and 36 meters during the day and are most commonly caught between June and October. The white shrimp, in contrast, is caught in muddy, sandy bottoms less than 18 meters deep between September and December. Differing from both pink and brown shrimps, the white species usually remains unburied during the day. Young white shrimp apparently prefer softer substrata than the other species (Williams, 1958).

Unexplainable natural fluctuations in numbers of shrimp occur for all three species with a portion probably attributable to disease. Gunter and Edwards (1969) did show a correlation with rainfall and the catch of white shrimp in Texas. This relationship, however, did not hold true in Louisiana, where freshwater discharge was greater, or for brown shrimp, possibly because the populations were already in nearly optimal habitats not so influenced by an increase or decrease in rain.

Materials and Methods

The majority of shrimp that were examined were from 0.25-acre ponds on Grand Terre Island, Louisiana, where, between 1969 and 1972, the Louisiana Wild Life and Fisheries Commission conducted several different rearing experiments with white and brown shrimps. Broom (1968) described the construction of these shallow, 0.7-0.9 m deep ponds. Water was continually pumped in through a 0.25-mm mesh filtering sock covering the intake pipe and drained out through a standpipe. A 1.8 × 3.6 × 0.5 m catch basin aided in harvesting shrimp from the slightly sloping pond. Shrimp obtained for the present study were usually collected a few days before final harvesting with a small trawl and then maintained in 0.09-m^3 aerated plastic containers until examination. Each shrimp was measured in millimeters from the tip of the rostrum to that of the telson, sexed, and dissected. Teasing apart and separating the gills, stomach, hepatopancreas, midgut, hindgut, gonads, and muscle tissue allowed critical examination with a compound or stereomicroscope. Notes

on numbers and species of all parasites found were recorded, and representative material was fixed in buffered formalin, AFA solution (alcohol-formalin-acetic acid), Bouin's solution, or ethyl alcohol and stored. When necessary, an estimate of the number of parasites replaced an exact count. In the case of a colonial ciliate on the gill filaments, a convention was adopted: A few scattered colonies were considered a very light infestation and given an intensity value of 1.0. A light infestation (= 2.0) usually consisted of several colonies evenly distributed over the gill surface, a moderate one (= 3.0) had several scattered clumps of many colonies, and a heavy one (= 4.0) had either large clumps over much of the surface or an even distribution of many ciliates. The values are obviously subjective, especially when assigned by more than one person, but are a reasonable estimate of the infestations. All the readings for an experiment dealing with stressed shrimp were made by one individual.

Commission personnel fixed samples of the shrimp that were used to stock ponds at Grand Terre and the brown shrimp harvested 16–17 July 1971 in l0% formalin; all other shrimp were examined fresh. The Commission supplied information on the studies. Neal and Latapie, who did the rearing experiments, presented a detailed account of the shrimp, ponds, experiments, and results. Basically, different types of feed were used in 1969, rates of stocking were varied in 1970, and the amount of feed was varied in 1971. The food consisted of commercial pellets in all experiments except in 1969 when ground fish and cornmeal were also used. Stomachs of some of the pond-reared shrimp contained small invertebrates, which, presumably, depended on excess commercial feed.

Material from other rearing experiments was also examined. This included brown shrimp reared for a little over a month in floating cages, or baskets, by the Alabama Department of Conservation at Dauphin Island, Alabama, in the summer of 1971. The cages were made from vinyl-coated hardware cloth about 0.9 m in diameter by 1.2 m high and described by Swingle (1971). The bottom of the cages remained over 0.4 m from the substratum. Live pink shrimp from abnormally cloudy ponds at University of Miami's Turkey Point facility were received from Florida on 9 September 1971; pink, white, and brown shrimps fixed in 1969 and 1970 were sent by the Texas Parks and Wildlife Department at Palacios, Texas; and fixed white and brown shrimps with microsporideans from Ossabaw Sound, Georgia, were sent in June 1972.

Specimens of shrimps from near Grand Terre, Louisiana, and from Mississippi Sound and adjacent waters were examined in order to compare their parasites with those of pond-reared hosts.

Parasites and Diseases

Common reported parasites and diseases

Microsporideans cause the most conspicuous diseases. Each of four known species in penaeid shrimps in the northern Gulf of Mexico will be discussed. The first, *Nosema nelsoni* Sprague, 1950, is one of three species which infect the tail of shrimps, making it chalky white in appearance and "cottony" in texture. Because of these characteristics, shrimp infected with any of the three are known as "milk" or "cotton shrimp." The fresh spores of *N. nelsoni* are single and approximately 2.5 μ long × 1.5 μ wide with a narrow polar filament

approximately 23 μ long with 7–10 undulations, although specimens from Mississippi have been recorded as large as 3.5 μ × 2.3 μ. A microsporidean spore will be slightly smaller when preserved in a fixative. Typically found surrounding the bundles of abdominal muscles, *N. nelsoni* commonly infects brown and white shrimps in Mississippi, Louisiana, and other areas in and adjacent to the Gulf. It was reported from the pink shrimp in Florida (Hutton et al., 1959). Brown shrimp from Ossabaw Sound, Georgia, are also infected. Sprague and Couch (1971) discussed other possible hosts of *N. nelsoni*, as well as other protozoans found in decapod crustaceans.

The gross appearance of an infection with *Pleistophora* sp., the second microsporidean, is similar to and cannot always be distinguished from one with *N. nelsoni*. Extensive bluish-black pigmentation in chromatophores develops primarily along the dorsal and dorso-lateral surfaces of shrimp infected with both species, but it is usually more developed in hosts infected with *Pleistophora* sp. Baxter et al. (1970), without a description, first reported *Pleistophora* sp., and Melvin J. Contransitch (1970) described it in a presently unpublished master's thesis. Fresh spores are slightly pyriform, 2.3–3.0 μ long by 1.7–2.5 μ wide (averaging 2.6 μ × 1.9 μ, with a uniform capsule 0.5 μ wide and a polar filament 53–125 μ long × 0.3 μ wide along its entire length. Fresh specimens in Mississippi, which I consider to be the same species, were 1.7–2.0 μ × 0.9–1.3 μ with filaments 42 μ and longer. Spores of *Pleistophora* sp. develop in either large or small sporonts, or cysts, which are spherical to irregular in shape. Small cysts, 11–24 μ in diameter, contain 14–130 spores and the larger ones, up to 55 μ wide, can contain several hundred spores. Rather than surrounding the striated abdominal muscles like *N. nelsoni*, this species usually replaces the muscle tissue. *Pleistophora* sp. is also found, but less frequently, in the heart, hepatopancreas, gills, and stomach. It commonly infects brown and white shrimps in Texas, Louisiana, and Mississippi. Infections also occurred in white shrimp from Ossabaw Sound, Georgia.

A third species, *Thelohania duorara* Iversen and Manning, 1959, most commonly infects the pink shrimp but has been reported from the Caribbean brown shrimp, *P. brasiliensis* Latreille (see Iversen and Van Meter, 1964). Kruse (1959) reported what is apparently the same species in pink, brown, and white shrimps. Spores of this species usually lie between muscle fibers but may completely replace that tissue or infect the heart, gonads, brain, and musculature throughout the host. When fresh, the pyriform-shaped spores range in size from 4. 7–6.8 μ long by 3.0–4.2 μ wide (averaging 6.0 × 3.7 μ) with a uniformly wide polar filament 97–142 μ long, and eight such spores are in sporonts 8.5–13.6 μ in diameter. Pink shrimp infected with *T. duorara* extend as far west as Biloxi Bay, Mississippi (Edward Whatley, Jr., personal communication).

The final species is easy to tell from others. *Thelohania penaei* Sprague, 1950 is usually located along the dorsal midline of the white shrimp. It infects smooth muscles of the blood vessels, foregut, hindgut, and the germinal tissue of the gonads. Infections seen under the carapace in the branchiostegal epithelium and in the appendages originate from muscles of the blood vessels. Edward Whatley, Jr. (personal communication), who has sectioned several infected individuals, has observed spores in intestinal columnar epithelial cells but never in striated muscle cells. In white shrimp from Georgia, however, spores were located around the fibers of the dorsal abdominal muscles. The distinctly pyriform spores are found in groups of eight in the sporont, which is characteristic of the genus *Thelohania*

Henneguy, 1892. There are both microspores which measure 2.5–4.7 μ long × 2.0–3.5 μ wide, averaging 4.0 × 2.3 μ, and megaspores which are 5.5–8.2 μ × 3.5–4.2 μ. The polar filaments protrude 65–87 μ, averaging 74 μ, with a uniformly thick proximal portion and a thin distal portion following a transitional tapering zone. Sporonts are 7–12 μ wide, averaging 9.3 μ. White shrimp sent from Palacios, Texas, and Ossabaw Sound, Georgia, were infected, as were many shrimp in Louisiana and Mississippi. More unusual were specimens of pink and brown shrimps that had been reared together in a pond at Palacios. These shrimp had infections in dendritic patterns only in the gills. Only microspores, averaging 3.5 × 2.3 μ with typically shaped filaments 45 μ long, were noted. According to Larry Elam (personal communication) at Palacios, no other similarly appearing infections have occurred.

Shrimp can be infected with more than one species of sporozoan. In Mississippi, individual white shrimp containing *T. penaei*, *N. nelsoni*, and *Pleistophora* sp. were observed. Figure 1 illustrates a dual infection in the same host.

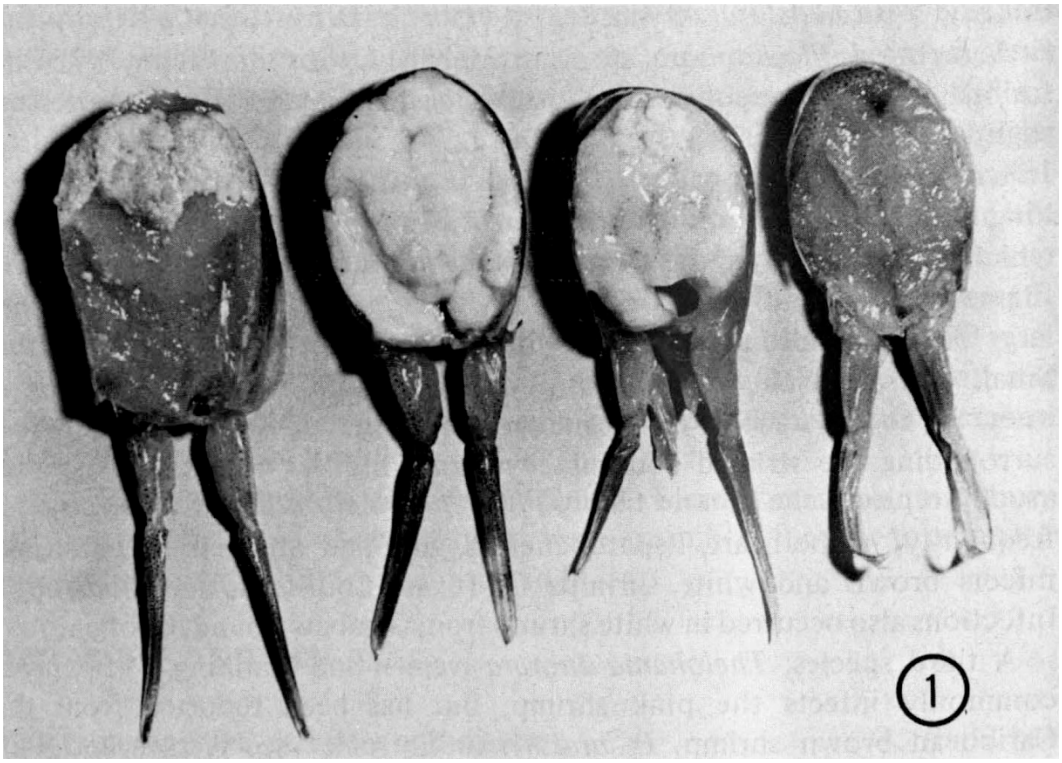


Figure 1. First abdominal segments of white shrimp collected from Calcasieu Bay, Louisiana, showing from left to right: *Thelohania penaei* in female, *Nosema nelsoni* in female, *T. penaei* and *N. nelsoni* in male, and uninfected female.

Considerable work needs to be undertaken on various aspects of microsporidean infections to find if additional penaeid hosts and additional microsporidean species occur and to discover what effect the infections have on the individuals and the populations. Iversen (1969) reported what he thought was a microsporidean from the American white shrimp, *P. schmitti* Burkenroad, in Venezuela, and presently, J. R. Sampson and E. S. Iversen are describing a new species of *Nosema* Nageli, 1867 from that host as well as another from the royal red shrimp, *Hymenopenaeus robustis* (Smith), and a new species of *Thelohania* from the rock shrimp, *Sicyonia breverostris* Stimpson. Other infections from India and Africa were cited by Sprague and Couch (1971). Infected shrimp can be castrated; they can be weakened and killed, especially when under additional stress.

No experimental infection with any microsporidean has been confirmed in penaeid shrimps in spite of numerous attempts (see Roth and Iversen, 1971). Transmission of the organism has been reported for several nonpenaeid hosts. Summerfelt and Warner (1970) listed several species which have been transmitted by direct oral ingestion of spores, and Kellen et al. (1966) discussed transovarian transmission of *Thelohania* spp. in mosquitoes. It was quite possible that the European stickleback had to feed on small crustaceans recently engorged with spores of *Glugea anomala* Moniez rather than feeding directly on the spores to become infected (Weissenberg, 1968). Earl Weidner (personal communication) has confirmed that priming was necessary for infection of *Glugea stephani* (Hagenmüller, 1899) Woodcock, 1904 in the winter flounder, *Pseudopleuronectes americanus* (Walbaum). Spores had to be passed through a suitable crustacean host before they would discharge in the fish. He used amphipods and isopods.

Confusion exists about the taxonomy of many species. Species are usually defined by the size and shape of the spore and the host that is infected. But Hazard and Weiser (1968) discussed two different types of spores for *Thelohania legeri* in mosquitoes, one of which had been previously described as a species of *Nosema*.

In addition to microsporideans, shrimps in ponds often harbor cephaline gregarines. Most common of these is *Nematopsis penaeus* Sprague, 1954, which, according to Kruse (1966a, 1966b) and Sprague and Couch (1971), who discussed hosts in addition to pink, brown, and white shrimps, may be more than one similar species. Syzygy in *N. penaeus* is multiple with as many as seven trophozoites in straight or forked chains which may total over 0.5 mm in length. The primary satellite ranges from 80 to 275 μ long and is narrow, 40–70 μ wide. The opaque trophozoites can be readily observed with a stereomicroscope but must be examined under a compound scope to convince one who is observing them for the first time that he is observing a gregarine. Attached to the wall of the rectum, the spherical reproductive cyst, or gametocyst, is up to 240 μ in diameter. The necessary intermediate host remains unknown.

For *N. duorari* Kruse, 1966, however, the pelecypod molluscs *Aequipecten irradians* Lamark, *Cardita floridana* Conrad, *Chione cancellata* Linnaeus, and *Macrocallista nimbosa* Solander all serve as hosts. This species, found in pink shrimp, could not be transmitted to white or brown shrimp by Kruse (1966a, 1966b), but in most stages is identical in appearance to *N. penaeus*. Characters used to differentiate *N. duorari* from *N. penaeus* include a larger average size of gymnospore developing in the gametocyst (9.4 μ compared to 6.3 μ) and the

incorporation of the above-mentioned bivalve molluscs as intermediate hosts. The gametocysts of *N. duorari* are usually embedded in the anterior portion of the rectum rather than distributed throughout it.

The gymnospores from brown shrimp average larger than those from white shrimp. Also suggesting that there are different species in the two shrimps were experiments in which Kruse (1966b) kept naturally infected brown shrimp, not usually found in Alligator Harbor, Florida, and naturally infected white shrimp isolated in aquaria with a continuous flow of unfiltered seawater from the Harbor. The brown shrimp lost their infection by the eighth day, with young trophozoite stages disappearing by the third day, whereas the infection decreased in white shrimp for a week but remained with the presence of young trophozoites for another week until termination of the experiment. When the seawater was unchanged, all infections were gone after ten days and remained so for at least another 15 days. White shrimp apparently acquired new infections from spores either in the water or in small invertebrates, but the brown shrimp in contact with the same agents did not. Additional studies with intermediate hosts are necessary to understand better the different species of *Nematopsis*.

Another gregarine which infects pond-reared shrimp is *Cephalolobus penaeus* Kruse, 1959. It is usually found attached near the duct of the hepatopancreas at the base of the lappet and filter of the gastric mill. There is no true epimerite, but the anterior portion of the protomerite of the primite, a solitary trophozoite, is modified with a peripheral ridge containing up to 40 lobe-like processes. The primite typically has one but may have two or three satellites associated with it. Up to 0.7 mm long in associations, the gregarine has been reported from brown and pink shrimps only. During this study, it was observed in white shrimp from Barataria Bay, Louisiana.

A peritrich ciliate was identified as *Zoothamnium* sp. by Villella et al. (1970) and Johnson et al. (in press) but not discussed in detail. Pink shrimp sent to me from the same location, Miami, were infested with a species of *Zoothamnium* Bory which appeared identical to ones recovered by me from the gills and exoskeleton of many shrimp discussed later in this study (see Figs. 2–4) and whick was also present on white and brown shrimps from both Palacios, Texas, and Ossabaw Sound, Georgia. Infestations of this common branching vorticellid were apparent on shrimp as young as postlarval forms in Mississippi Sound.

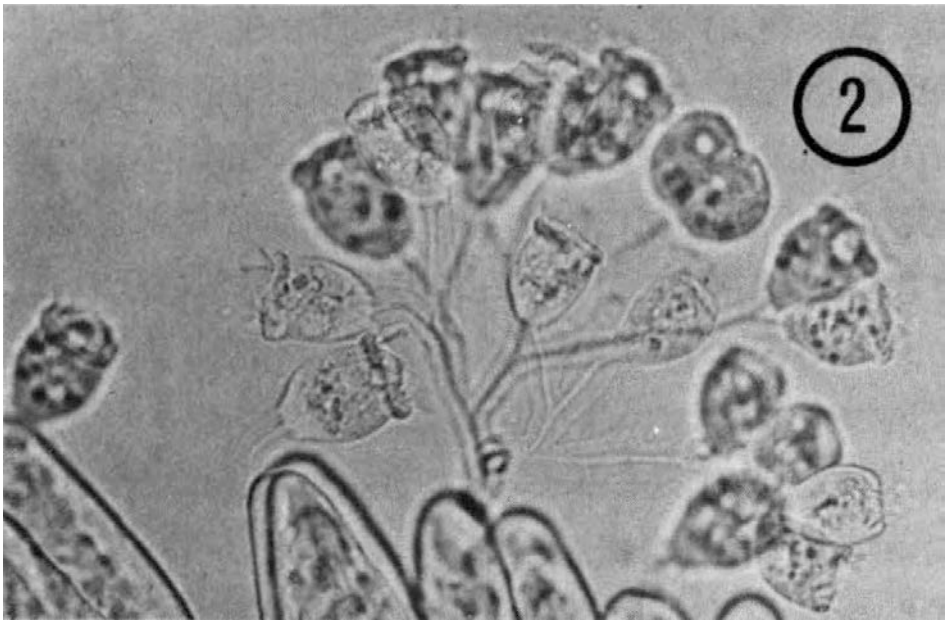


Figure 2. *Zoothamnium* sp. on gills of brown shrimp. A medium-sized living colony.

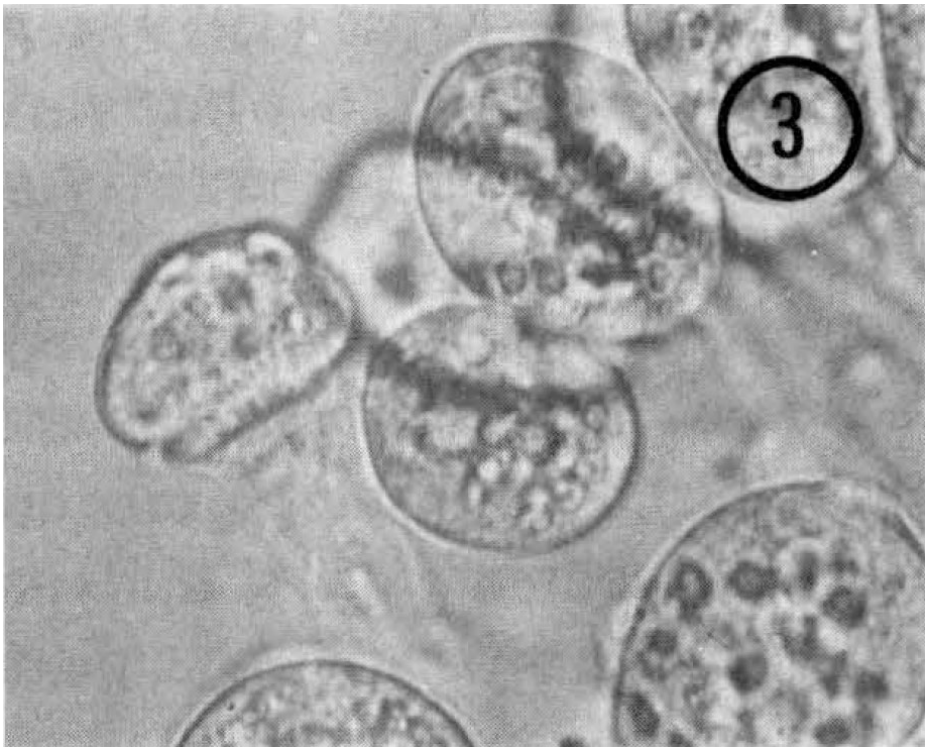


Figure 3. *Zoothamnium* sp. on gills of brown shrimp. A developing ciliospore and withdrawn individuals, living.

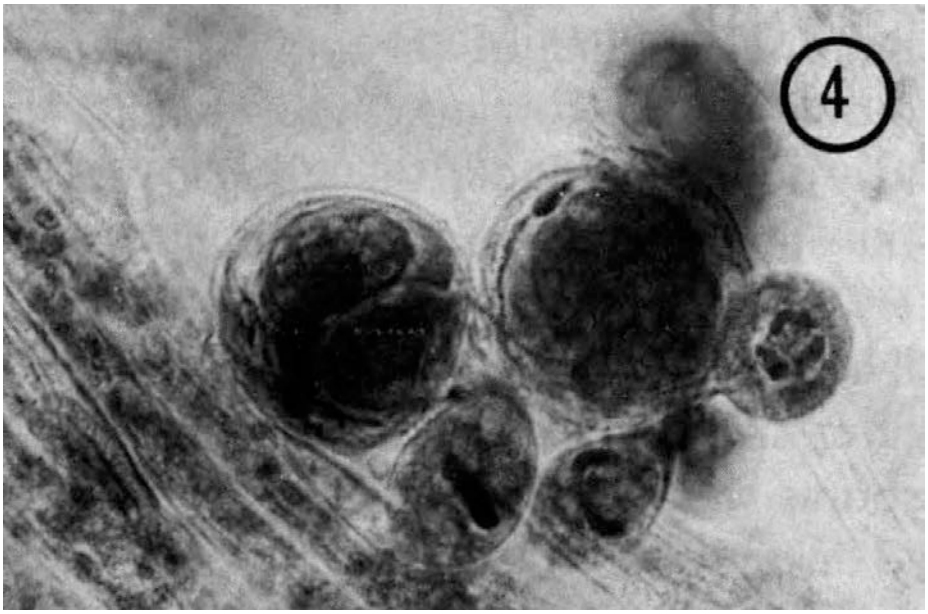


Figure 4. *Zoothamnium* sp. on gills of brown shrimp. A dividing stage, stained with hematoxylin.

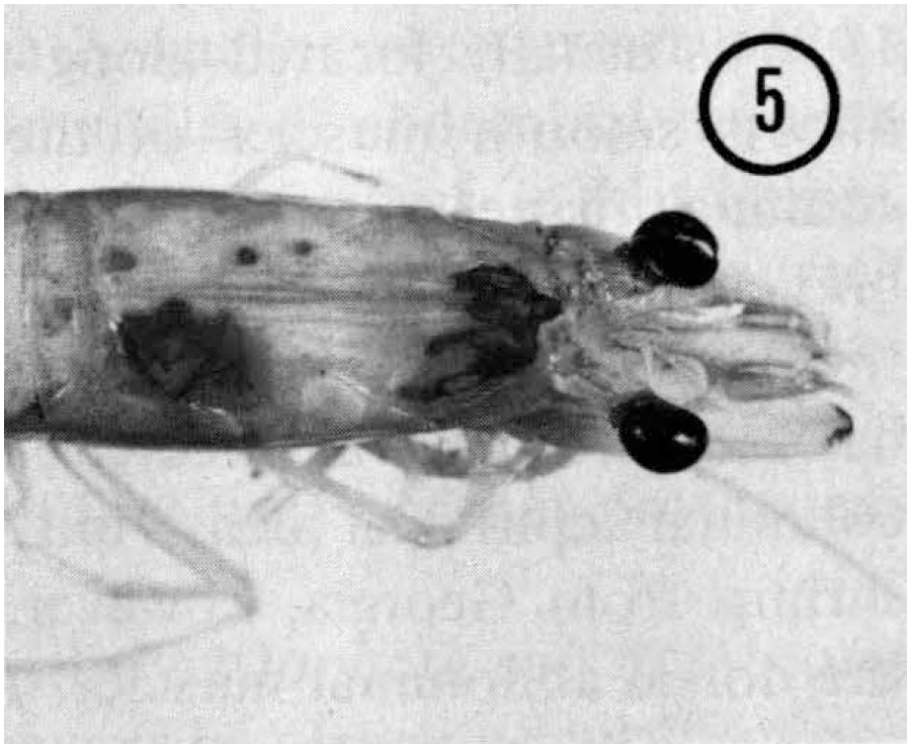


Figure 5. A preserved brown shrimp with deteriorated areas associated with chitinoclastic bacteria.

Variation existed in the size of individual trophonts, and reproductive stages commonly occurred in a portion of some colonies of *Zoothamnium* sp. Telotrochs, or free swimming ciliospores were produced. Within the stalks of a colony, myonemes were usually continuous, a characteristic of members of the genus *Zoothamnium*, causing them to contract or expand simultaneously. Occasionally, however, individual myonemes were not connected at junctions or along the stalk, suggesting a species of *Carchesium* Ehrenberg. I considered those individuals to be abnormal specimens of *Zoothamnium* sp. but did differentiate some additional specimens discussed below.

A few specimens from brown and white shrimps, primarily in Mississippi but also in Louisiana, were lacking myonemes. These were primarily on appendages rather than gill filaments. Because whole colonies were devoid of apparent myonemes, and they could be clearly separated from *Zoothamnium* sp. by their morphology and contractibility, they are considered a species of *Epistylis* Ehrenberg. A recent note by Johnson (1972) discussed infestations of *Epistylis* sp., but photographs and specimens sent to me by S. K. Johnson revealed myonemes which were connected where stalks branched, suggesting that the ciliates were the same as those considered *Zoothamnium* sp. in this paper. Hutton (1964) reported a ciliate identified as *Epistylis* sp. from pink shrimp in various localities in Florida, but that identification should be confirmed.

The larval trypanorhynch cestode *Prochristianella penaei* Kruse, 1959 can be seen commonly in the tissues surrounding the hepatopancreas without dissecting the host. It is also found in the hepatopancreas and tissues and spaces adjacent to that organ. The white larva can obtain a length of over 3 mm when excysted from its vesicular blastocyst and can be identified by the structure and arrangement of hooks on each of four protrusible tentacles on the scolex, as described by Kruse (1959). Found as a larva in the white, brown, and pink shrimps as well as in *Trachypeneus constrictus* (Stimpson), it matures in the Atlantic stingray, *Dasyatis sabina* (Lesueur), and probably other rays. Aldrich (1965) and Ragan and Aldrich (1972) discussed ecological aspects of the larva in natural populations. Two additional trypanorhynch larvae from a similar site in the host, *Parachristianella monomegacantha* Kruse, 1959 and *Parachristianella dimegacantha* Kruse, 1959, were both described from the pink shrimp from one or two specimens. Corkern (1970), however, found *P. dimegacantha* present in 23% of the brown shrimp he examined from Galveston Bay, Texas. He reported an average infection of 2.3 worms per infected individual with a range between 1 and 24. Infections were more common in smaller shrimp. The worms differed somewhat from Kruse's (1959) description by having longer muscular bulbs in the scolex and a smaller blastocyst with less space between it and the bulbs.

An unidentifiable larval cestode is present in the intestine of shrimp in large numbers. Hutton et al. (1959) questioned whether it was a lecanocephalan, Kruse (1959) did not identify it, and Villella et al. (1970) referred to it as *Polypocephalus* sp., a lecanocephalid. I do not think it should be named until the adult form or more information is known. The larva is between 0.1 and 0.3 mm long (not 1.5–1.7 mm as mistakenly reported by Hutton et al., 1959) and has a prominent eversible apical sucker. Hutton et al. (1959) tentatively identified the same worm from four shrimps in addition to the brown and pink shrimps. They additionally found it in the nerve cord and cephalothoracic musculature. I found it in the

white shrimp, a new host record. It is not unusual to find a shrimp with over 1000 larvae, but rarely will all the shrimp in any given sample be infected.

Other reported parasites and diseases

The above parasites may be common among reared shrimps, especially if the shrimp were stocked as wild postlarvae. Several other parasites, however, have been reported from penaeid shrimp, but I found them rare or absent in reared hosts.

Fungi and bacteria, about which little is known, infect and destroy numerous shrimp. Black gill disease of the Kuruma prawn, *Penaeus japonicus* Bate, was assumed from experimental evidence to be caused by an imperfect fungus tentatively called *Fusarium* sp. (Egusa and Ueda, 1972). Harry Cook (1971) reported large-scale mortalities of hatchery-reared shrimp at Freeport, Texas, where *Lagenidium* sp. and another species of fungus similar to *Dermocystidium* caused mortalities within two to three days. Another unidentified species appeared as black spots and killed juvenile brown shrimp after spreading to the gill region. He also had major problems with bacteria belonging to the genus *Vibrio* in juvenile shrimp (Sindermann, 1971).

Trematode metacercariae of *Opecoeloides fimbriatus* (Linton, 1934) Sogandares-Bernal and Hutton, 1959 encapsulate in thin cysts in the host tissue surrounding the hepatopancreas, gonads, stomach, heart, and intestine, and also in the soft tissues of the head and under the exoskeleton. The worm, usually less than 2 mm long when excysted, has an accessory sucker and a pedunculated acetabulum possessing approximately six small papillae on each of its four lobes, plus larger ventral papillae. Kruse (1959), Hutton et al. (1959), and Sogandares-Bernal and Hutton (1959a) described the worm. It is common in penaeid shrimps during the summer months in Mississippi, including the brown shrimp, a host previously reported by Corkern (1970) only. It was also present in white shrimp from Ossabaw Sound, Georgia. The larva matures in several members of the family of drumfishes (Sciaenidae) and a few other fishes. Adults are commonly observed in Mississippi.

Other trematode metacercariae in the Gulf of Mexico are more rare. Two unidentified species of the microphallid *Microphallus* Ward, 1901 are described from the body musculature of pink shrimp along the west coast of Florida by Hutton et al. (1959a, 1959b) and Sogandares-Bernal and Hutton (1959b). An unidentified microphallid metacercaria was present in the abdominal muscles of a 24-mm-long preserved white shrimp from Barataria Bay on 29 April 1970. The cysts from this seasonally uncommon shrimp were 93–95 μ × 77–83 μ or smaller than those reported by Hutton et al. (1959) which were 153–170 μ and three to four times that size in diameter. Those authors also reported a metacercaria from the surface of the hepatopancreas tentatively identified as *Parorchis* sp.

A larval ascaroid nematode, or nematodes, identified by Kruse (1959), Hutton et al. (1959), Hutton et al. (1962), and Corkern (1970) as *Contracaecum* sp. is a member of and consequently should be transferred to the genus *Thynnascaris* Dollfus, 1933. The genus was reestablished by Hartwich (1957) and is in common use in recent publications. The relatively short intestinal caecum and proportionally longer ventricular diverticula, combined with the position of the excretory pore near the nerve ring, support the assignment as *Thynnascaris* which has members found as adults in fishes rather than in birds or mammals as do members of *Contracaecum* Railliet and Henry, 1912. Hutton et al. (1962) reported the

worm from several penaeid shrimp. In a project at the Gulf Coast Research Laboratory, Donald E. Norris found infections in 31% of 725 white and brown shrimp from Mississippi Sound and adjacent waters during the summer of 1972. There was an average of 2.8 larvae per infected individual with shrimp over 160 mm long having 57% of the larvae. Corkern (1970) suggested that brown shrimp could acquire worms by feeding on other infected shrimp.

There are reports of isolated infections by other parasites. Hutton et al. (1962) mentioned that single unidentified juvenile nematodes were found in the pink shrimp from the Campeche Bank shrimping grounds and in *Trachypeneus similis* (Smith) from the Dry Tortugas area off Florida. A single larval sarcophagid fly larva was reported by Hutton et al. (1959) and Hutton and Eldred (1958) from a spermatophore of a pink shrimp. This was most likely an accidental or postmortem infection.

Crustacean parasites are conspicuously absent from penaeid shrimps from the Gulf and Atlantic coasts, whereas bopyrid isopods are commonplace on other shrimps. Dawson (1958) found a high percentage of large *Penaeus semisulcatus* de Haan in the Persian Gulf parasitized by a bopyrid. Hutton et al. (1959) did report an unidentified crustacean parasite, "perhaps a rhizocephalan," from a pink shrimp in Boca Ciega Bay, Florida.

Fouling organisms can become established on shrimp during interecdysal periods. Dawson (1957) reported *Balanus amphitrite niveus* Darwin and *B. improvisus* from the white shrimp in South Carolina and an unidentified species of *Balanus* from Mississippi. Joyce (1965) recovered one fouled white shrimp in Florida.

Opaque muscles are often observed in shrimp that have been stressed. Rigdon and Baxter (1970) described this condition in brown shrimp and suggested it was caused by high temperature, anoxia, and stress. Venkataramaiah (1971a, 1971b) induced this condition, consisting of degenerated foci of striated muscles, with crowding, with depletion of dissolved oxygen, or by suddenly changing the salinity or salinity-temperature combinations of the water. This localized necrosis can cause death in either brown or white shrimp within 24 hours but appears to clear up rapidly in some afflicted individuals when they are placed in a more favorable environment. The diseased condition can occasionally be mistaken for microsporidiosis, but the reverse seldom occurs.

Shrimp produce an internal exoskeletal intrusion when tagged with a Petersen disc tag. This wound-repair process, described in brown shrimp by Fontaine (1971), consisted of an exoskeletal tube completely surrounding the pin. Cellular aspects of this process and of postmortem changes in brown shrimp are presently being studied by D. V. Lightner and C. T. Fontaine at the National Marine Fisheries Service Biological Laboratory in Galveston, Texas.

Unreported parasites and diseases

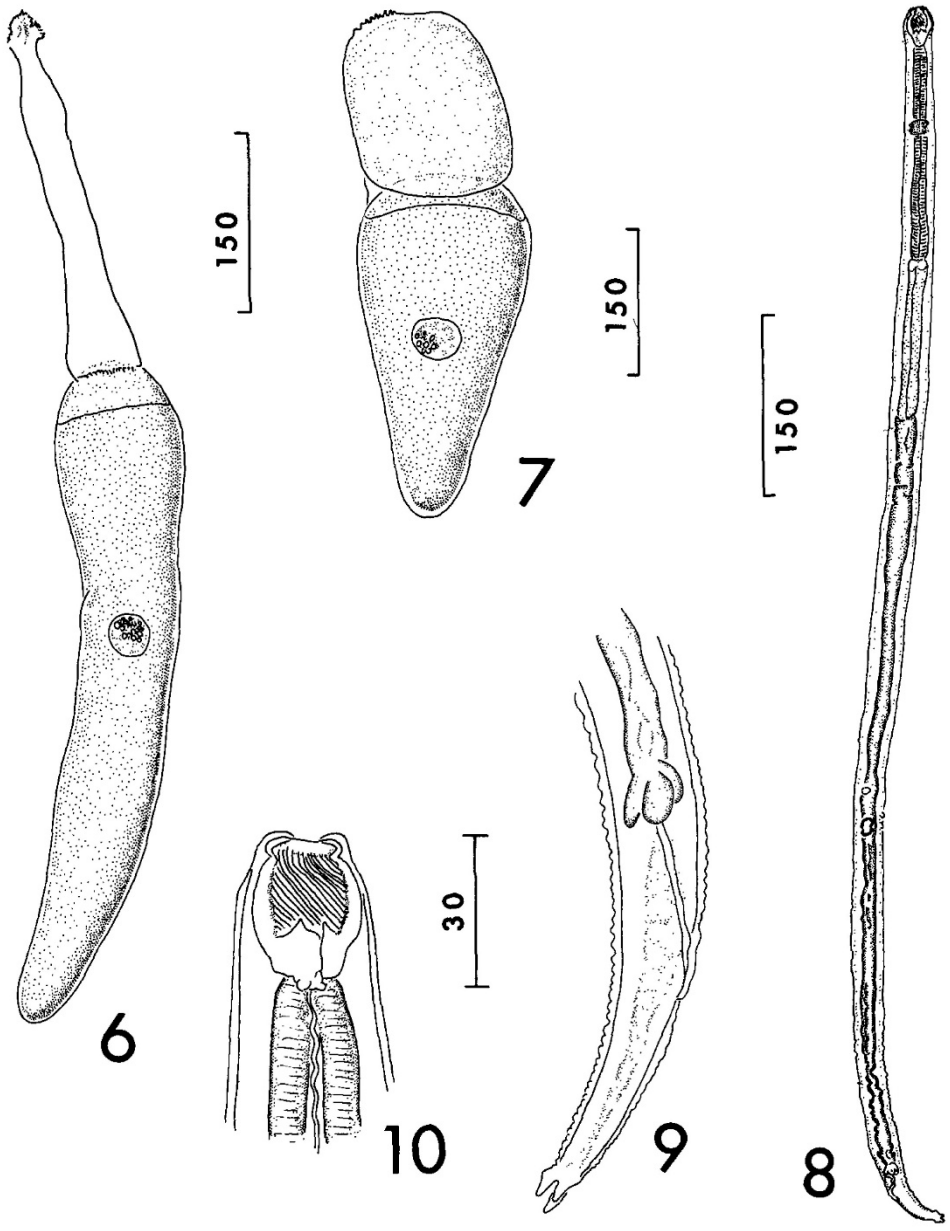
Several other organisms that infested shrimp, but had not been previously described or reported, were encountered during this study. Unidentified ciliates, in addition to *Zoothamnium* sp. and *Epistylis* sp., were present on the gills of shrimp, but were not numerous, and most of them were probably not specifically associated with the shrimp. There was one associated species of holotrich encysted in a thin membrane within the filaments of several brown shrimp in Davis Bayou in Ocean Springs, Mississippi. Since several species

of ciliates infest most of the decapods in Mississippi Sound and adjacent water and they are a potential threat to shrimp in rearing facilities, considerable attention needs to be given to the taxonomy, physiology, and pathology dealing with that group.

Several specimens of an undescribed gregarine were collected from the brown shrimp in Barataria Bay, Louisiana, on 16 July 1970. Further attempts to gather additional material were fruitless. Only the trophozoite stage was observed, and it was attached to the stomach strainer. Measurements were taken of eight individual trophozoites and two satellites (see Figs. 6 and 7). The trophozoite, 468–571 μ long, was divided by a conspicuous ectoplasmic septum into an anterior protomerite 29–58 μ long and a posterior deutomerite which was widest at the anterior, 77–159 μ wide, and tapering into a blunt posterior end. The protomerite possessed an elongated attached epimerite, at least 261–346 μ long × 40–74 μ wide at the posterior attachment. The anterior was firmly attached to the host, but all specimens were removed, and the morphology of the junction is unknown. The approximately spherical nucleus, 27–44 μ in diameter, was 140–263 μ from its center to the anterior edge of the protomerite. This nucleus was only in the deutomerite and contained about 9 to 17 granules. Linear syzygy was observed in two instances. The satellite was 302–362 μ long × 138–183 μ wide at the anterior end with a protomerite 26–32 μ long. The nucleus was similar to that described above except the granular material was less distinct.

The identification of this gregarine is uncertain until more specimens and possibly additional stages are examined. Gordon H. Ball (personal communication) thought additional material might reveal it to be a member of the Uradiophoridae Grasse, 1953, a family with species known from crustaceans.

Two specimens of a third-stage nematode larva of the genus *Spirocamallanus pereirai* (Annereaux, 1946) Olsen, 1952 (see Figs. 8–10) were obtained from the intestine of white shrimp in Back Bay of Biloxi, Mississippi, fixed in glacial acetic acid, and studied in glycerine after evaporation of 95 parts of 70% ethyl alcohol. The larva was 1.00–1.01 mm long × 30 μ at the widest level which was at the esophageal-intestinal junction; the width gradually tapered off posterior to that level. The tail terminated in four small rounded processes: The buccal capsule, 30 μ long × 18–21 μ wide, was continuous with numerous, approximately eleven, internal, narrow, occasionally interrupted, spiral thickenings. In the capsule there were, at least, three internal teeth, rounded in one specimen and pointed in the other. An external projection with two or three knobs fits into the muscular esophagus. The esophagus had anterior muscular and posterior glandular portions. The muscular portion, 177–180 μ long, had an internal cuticular lining and was surrounded with a poorly developed nerve ring; the glandular portion, 123–139 μ long, included a portion projecting into the prominent intestine. There were three large rectal glandular cells at the posterior end of the intestine. An obvious genital primordium is located next to the intestine 2/3 length of body from anterior end. The distance from the anus to the tip of the tail was 49 μ.



Figures 6 and 7. Undescribed gregarine.
Figure 6. Trophozoite with torn organelle of attachment.
Figure 7. Satellite.

Figures 8–10. *Spirocamallanus pereirai*.
Figure 8. Entire larva.
Figure 9. Posterior end of different specimen.
Figure 10. Anterior end.

Even though mature *S. pereirai* do not have internal teeth within the buccal capsule, three larval worms, 1.26–1.77 mm long from the spot, *Leiostomus xanthurus* Lacépède, had well developed ones. Characteristics of the more developed larvae from the spot, a common host for *S. pereirai* along with the Atlantic croaker, *Micropogon undulatus* (L.), and several other fishes, agreed with those of larvae from the shrimp in most respects such as the number of spiral thickenings in the capsule, number of rectal gland cells, and number of conical tips on the tail. The proportions of the internal structures were similar, with the genital primordium located 57–59% of the body length from the anterior end. In contrast to the larvae from the shrimp, the lumen of the intestine was distinct, as were two distal glandular esophageal nuclei and the nerve ring.

Fishes infected with S. *pereirai* feed on penaeid shrimps; however, shrimp may be a paratenic host acquiring the infection from an infected copepod or other host. Large numbers of first stage larvae from female worms in the spot were fed to 18 laboratory-reared and dry-food-fed brown shrimp 15–28 mm in length. Two or more shrimp were then critically examined 1, 2, 5, 9, 16, 21, and 34 days after being fed. Only on the twenty-first day was there an infection and there was but one larva. Perhaps a copepod, inadvertently present in the closed aquarium, became infected and was fed on by the shrimp. In any event, shrimp apparently act as intermediate hosts for the common worm.

What appears to be, at least, a facultative commensal nematode was found in both brown and white shrimps from Barataria Bay, Louisiana. The same or a similar species was also in shrimp from Ocean Springs, Mississippi, and Dauphin Island, Alabama. Numerous adult and juvenile *Leptolaimus* sp. (family Leptolaimidae Oerley, 1880) were obtained from the gills, stomach, hepatopancreas (both within and surrounding the caeca), midgut and hindgut of preserved shrimp during different seasons in Louisiana. Distinguishable from other nematodes in shrimp, it has a muscular bulbous posterior portion of the esophagus, setae about the anterior end, a tapering tail with a terminal swollen knob, and a male with two spicules, a gubernaculum, and four conspicuous sclerotized supplemental structures opening externally a short distance anterior to the anus. Five of one sample of 78 worms were juveniles. The worms, most common in the area of the hepatopancreas, were not disrupted or digested as were most dietary items, and several shrimp contained living specimens of this or a similar species after two days in an aerated container when all food items had been digested. On two occasions *Leptolaimus* sp. was found in pond-reared shrimp, once on the gills and once in the caeca.

Of the 29 species of *Leptolaimus* de Man, 1876 which typically inhabit a muddy, sandy substratum, none have been reported to be commensal, according to W. Duane Hope and Donald G. Murphy, who are studying the specimens. They believe the specimens may represent a new species.

It is not presently known how the shrimp acquire the nematodes or how long the worms remain in their hosts. Looking from another aspect, free-living nematodes may play a role in the infection of shrimp by microsporideans. An unidentified species of *Pleistophora* reported by Hopper et al. (1970) infects most tissues of *Metoncholaimus scissus* Wieser and Hopper, 1967, a nematode living in habitats serving as nursery grounds for juvenile shrimp. Even though the spores, 3.8 × 1.5 μ, with filaments 2–10 times the length, differ from those

in shrimp, the possibility of an involvement of even this species with shrimp cannot be discounted.

Several specimens of the free-living desmodorid nematode *Croconema* sp. from the stomach and intestine of brown shrimp from Barataria Bay, Louisiana, were in poor condition, apparently partially digested, and not considered commensal. I also observed other free-living nematodes alive in shrimp. David Feigenbaum (personal communication), who is studying the parasites of *P. vannamei* Boone from near Mazatlan, Mexico, and *P. brasiliensis* near Miami, Florida, has found several different nematodes, some of which are free-living forms.

A single white shrimp in a pond open to high tides in Ocean Springs, Mississippi, harbored one specimen of *Myzobdella lugubris* Leidy, 1852. This dark colored leech, capable of stretching over 2 cm, commonly resides on the grass shrimp, *Palaemonetes pugio* Holthuis, and the blue crab, *Callinectes sapidus* Rathbun, and numerous estuarine fishes. It typically lives in water with low salinity.

Shrimp are infested by numerous bacteria, fungi, and algae. Studies by Cook and Loften at the Gulf Coast Research Laboratory have shown that the brownish deteriorated areas on the exoskeleton are associated with several species of chitinoclastic bacteria (see Fig. 5). Pink shrimp from ponds in Miami, Florida, in September, 1971 had species of *Vibrio*, *Beneckea*, and *Pseudomonas* associated with the deteriorated areas. These areas in brown shrimp maintained in aquaria by A. Venkataramaiah at the Gulf Coast Research Laboratory and white shrimp from ponds at Palacios, Texas, all contained species of *Vibrio* and *Beneckea*. The same or similar species were also obtained from shrimp without conspicuous brownish areas from ponds at Grand Terre, Louisiana, and from Bernard Bayou in Biloxi, Mississippi.

The only fungus collected from shrimp during this study was an unidentified phycomycete. It was found in 1971 and 1972 on brown shrimp both in ponds from and natural habitats near Grand Terre, Louisiana, and could not be cultured on seawater agar. Mycelium penetrated and covered the gill filaments. In some stained material from the same sample of hosts, the same or a similar appearing organism revealed no structures within the filaments. Of four infested shrimp maintained in an aerated container two days, at least two molted, and all lost observable indications of their fungal and ciliate infestations. Presumably, numerous different fungi play a major role in mortalities of wild and reared shrimp, most specifically larval and postlarval stages.

Attached to and wrapped around the gill filaments of reared shrimp in Grand Terre, Louisiana, and Dauphin Island, Alabama, was the filamentous blue-green alga, *Schizothrix calcicola* (Agardh) Gomont. This member of the Oscillatoriaceae can be found in the plankton and attached to various substrata. Its trichomes can calcify and become the primary organism responsible for laminated sedimentary structures, called "algal stromatolites," in Bermuda (Sharp, l969b). The alga exists as several different ecologically selected strains (Sharp, 1969a). Francis Drouet (1963), who identified and has in his collection some of the present material, revised *S. calcicola*, including 54 synonyms and giving a description of type and other material. According to Drouet (personal communication) and Sharp (1969b), the species grows on various plants and animals in both fresh and marine habitats.

Drouet informed me that he had no record of this or any other blue-green algae being responsible for mortality in crustaceans.

Several of the brown shrimp from cages at Dauphin Island, Alabama, were infested with the hydroid, *Obelia bicuspidata* Clark, 1876. In some shrimp, the eyes and appendages were completely covered by the encrusting animal. Apparently the fouling took place on the shrimp between abnormally long interecdysal periods and is not specific to crustaceans. Several hydroids, however, are specific to various invertebrates or other types of substrata as indicated by Fraser (1944), Dales (1957), Rees (1967), Calder (1971), and others. Many of the individual hydrothecae of *O. bicuspidata* on the shrimp were larger than those found in Virginia by Calder (1971), who redescribed the species.

An unusual condition in brown and white shrimps from Matagorda Bay, Texas, remained unexplained. Shrimp were "golden" in color. This color occurred throughout the tissues. In some, the muscle tissue was an opaque yellowish gold and in others transparent. Larry Elam, who found but one "golden shrimp" during the past several years in ponds at Palacios, Texas, said that the condition in Texas was rare in nature and that occasionally a shrimp would be half transparent and half opaque. One would expect many such pond-reared shrimp if the condition were caused by a dietary deficiency or an organism. Possibly, it is a rare hereditary disease that could be used as a "biological tag." J .Y. Christmas of the Gulf Coast Research Laboratory showed me one such shrimp collected off the Louisiana coast, but neither he nor I has heard of one in Mississippi. The condition is not to be confused with that when shrimp have obvious reddish or yellowish exoskeletons and normal musculature. Observed shrimp with abnormal pigmentation of the exoskeleton appeared normal after molting.

Incidence and Intensity

Summarized data for parasites observed in shrimp from Grand Terre Island and adjacent water between 1970 and 1972 appear in Tables 1, 3, and 5, with corresponding information on the hosts in Tables 2 and 4. The percentage of hosts infected is referred to as "incidence," and the number of a particular parasite per infected individual is referred to as the "intensity," with the rates given as the average number per individual per sample.

In addition to the hosts listed in the tables, a small number of reared and wild brown and white shrimps was also examined on 24–25 September 1969. All 15 white and five brown reared shrimp were infected with *Nematopsis penaeus*. Both species included individuals with well over 1000 trophozoites and 100 gametocysts. One brown shrimp had about 500 cysts. Every shrimp in sampled natural populations of both species was infected with *N. penaeus,* but usually with about 25 gametocysts and 50 trophozoites. A few wild and reared white shrimp harbored recognizable infections of *Thelohania penaei*, and light infestations of *Zoothamnium* sp. and *Epistylis* sp. Of five ponds with mortality rates less than 10% and approximately 3500 shrimp per pond, the incidence of infection with *T. penaei* was 0.0, 0.7, 0.8, 1.2, and 1.2% of the hosts. One inadvertently introduced brown shrimp was infected with *Pleistophora* sp. The intestinal larval cestode and *Thynnascaris* sp. infected wild brown shrimp.

Table 1. Parasites from penaeid shrimps at Grand Terre, Louisiana, in 1970

				Zoothamnium sp. on gills			*Prochristianella penaei*			*Nematopsis penaeus*						
										Trophozoites			Gametocysts			Both
Species of shrimp	Location	No. examined[1]	No. infected[2]	Incidence[3]	Range[4]	Intensity[5,6]	Incidence	Range	Intensity	Incidence	Range	Intensity	Incidence	Range	Intensity	Combined incidence
Brown	Canal[7]	41	34	71	VL-M	1.8	0[8]			0[8]			108	5–50	27	10[8]
Brown	Pond D-5	16	16	88	VL-H	1.6	31	1–3	1.8	81	20–1000	725	81	5–166	45	100
Brown	Pond D-4	18	18	72	VL-L	1.5	39	1–3	1.6	44	1–400	98	67	1–80	32	83
Brown	Pond D-16	17	17	100	VL-H	1.9	23	1	1.0	12	1–10	6	12	2–12	7	18
Brown	Pond D-15	18	18	100	H	4.0	22	1–2	1.3	78	2–300	93	83	3–87	27	100
Brown	Pond D-13	16	16	100	VL-M	2.6	31	1–2	1.4	13	2–50	26	25	1–14	8	31
Brown	Canal	16	16	100	VL-H	2.3	56	1–21	4.7	75	1–100	33	69	1–152	36	81
White	Canal	6	6	100	VL-M	2.2	67	2–5	4.0	100	8–100	36	100	3–97	31	100
White	Canal[7]	30	20	33	VL-M	2.0	33	1–4	1.8	3	100	100	40	1–24	8	40
White	Pond D-11	4	1	25	L	2.0	25	1	1.0	0			0			0
White	Pond D-9	21	17	47	L-M	2.6	19	1–5	2.0	43	3–50	19	52	1–56	18	67
White	Pond D-10	19	18	95	L-H	2.9	5	2	2.0	42	10–100	35	84	3–91	47	89
White	Pond D-7	20	18	90	L-H	2.7	25	1–6	2.2	20	25–400	156	50	1–26	10	60
White	Pond D-3	21	19	90	L-M	2.3	38	1–3	1.6	81	13–500	249	81	9–200	69	81

1. The total number of shrimp in sample.
2. The number of shrimp infected with any parasite.
3. The percentage of total individuals infected.
4. The number of parasites collected from the least and most infected shrimp.
5. The average number of parasites per infected individual.
6. Numerical values for intensity are very light, VL = 1; light, L = 2; moderate, M = 3; heavy, H = 4; see text for explanation of different intensities.
7. Shrimp used to stock ponds.
8. Values for *N. penaeus* based on 21 and for *P. penaeid* on 31 of the 41 examined shrimp.

Table 2. Information concerning penaeid shrimps at Grand Terre, Louisiana, in 1970

Species of shrimp	Location[1]	Number examined	Number of females	Date examined	Length of examined shrimp		Stocking rate per acre	Duration in pond in days before examined	Mortality rate at harvest (%)
					Range (mm)	Average (mm)			
Brown	Canal	41	25	4/29	31–69	45.3	used to stock ponds		
Brown	Pond D-5	16	10	7/15	100–125	112.7	15 000	77	19.9
Brown	Pond D-4[2]	18	5	7/15	84–96	90.1	20 000[2]	77	12.2
Brown	Pond D-16	17	6	7/16	97–120	105.3	20 000	78	14.0
Brown	Pond D-15	18	9	7/15	98–111	105.7	30 000	78	46.2
Brown	Pond D-13	16	14	7/16	104–118	110.2	35 000	77	69.3
Brown	Canal	16	8	7/16	51–124	94.4	used for comparison		
White	Canal	6	5	7/16	62–80	73.0	used for comparison		
White	Canal	30	19	7/14	37–67	45.6	used to stock ponds		
White	Pond D-11	4	3	9/22	92–98	95.7	15 000	80	20.4
White	Pond D-92	21	12	9/22	90–118	96.5	20 000[2]	80	21.3
White	Pond D-10	19	6	9/22	112–132	121.2	20 000	80	2.7
White	Pond D-7	20	8	9/23	110–125	118.1	25 000	80	0.0[3]
White	Pond D-3	21	10	9/23	117–140	126.5	30 000	80	21.8

1. The water in the ponds ranged between 23.4 and 33.2°C for temperature and between 15.1 and 23.3 ppt for salinity for the brown shrimp and between 14 and 31°C for the white shrimp.
2. Control ponds.
3. Stocking rate was underestimated.

Table 3. Parasites from penaeid shrimps at Grand Terre, Louisiana, in 1971[1]

				Zoothamnium sp. on gills			*Prochristianella penaei*			*Nematopsis penaeus* Trophozoites			Gametocysts			Both	Intestinal cestode		
Species of shrimp	Location	No. examined	No. infected	Incidence	Range	Intensity	Incidence	Range	Intensity	Incidence	Range	Intensity	Incidence	Range	Intensity	Combined incidence	Incidence	Range	Intensity
Brown	Pond D-7	20	8	40	VL-H	1.8	0			0			0			0	0		
Brown	Pond D-5	19	15	79	VL-L	1.1	0			0			0			0	0		
Brown	Pond D-4	18	11	61	VL-H	1.9	0			0			0			0	0		
Brown	Pond D-8	20	9	30	VL-H	1.8	0			0			40	1–15	6.3	40	0		
Brown	Pond D-3	20	17	85	VL-H	1.9	0			0			0			0	0		
Brown	Pond D-15	20	10	50	VL-H	1.4	0			0			0			0	0		
Brown	Pond D-16	20	20	95	VL-H	3.1	25	1–3	1.6	0			0			0	0		
Brown	Pond D-6	20	12	60	VL-M	1.4	0			0			0			0	0		
White	Canal A[2]	20	17	70	VL-M	2.4	10	1–1	1.0	15	3–80	32.7	20	3–34	20.0	25	40	5–600	166.7
White	Canal B[2]	20	20	45	VL-L	1.2	50	1–5	2.2	45	2–200	69.8	70	12–100	40.6	70	40	11–400	119.8
White	Pond D-10	15	15	100	VL-M	1.5	40	1–7	2.5	67	11–100	49.2	73	1–100	29.4	73	0		
White	Pond D-11	15	14	93	VL-H	2.4	40	1–5	1.8	0							0		
White	Pond D-12	15	15	100	VL-H	2.5	33	1–6	2.4	0							0		
White	Pond D-13	16	16	69	VL-M	2.0	80	1–10	2.6	31	1–500	109.8	56	1–75	17.1	69	0		
White	Pond D-14	16	16	94	VL-H	1.9	38	1–7	3.2	6	40	40.0	25	3–25	13.0	25	0		
White	Pond D-1	13	13	100	VL-L	1.5	23	3–5	4.3	23	1–4	2.0	54	1–144	49.6	54	8	100	100
Brown	Pond D-1	2	2	100	VL-L	1.5	100	8–10	9.0	100	1–75	38.0	50	4	4.0	100	0		
Brown	Hatchery[2]	20	0	0			0			0			0			0	0		
Brown	Pond D-2	15	15	100	VL-L	1.1	0			0			0			0	0		
Brown	Pond A-4	15	15	100	VL-M	1.8	0			73	1–125	39.3	33	1–200	80.4	73	0		
Brown	Canal	4	2	25	VL	1.0	0			25	50	50.0	50	6	6.0	50	0		

1. See footnotes in Table 1 for meaning of headings.
2. Shrimp used to stock ponds.

Table 4. Information concerning penaeid shrimps at Grand Terre, Louisiana, in 1971

Species of shrimp	Location[1]	Number examined	Number of females	Date examined	Length of examined shrimp		Stocking rate per acre	Duration in pond in days before examined	Mortality rate at harvest (%)	Daily feed (% of shrimp weight)
					Range (mm)	Average (mm)				
Brown	Pond D-7	20	9	6/30	93–115	102.2	20 000	62	21.3	variable > 5
Brown	Pond D-5	19	11	7/16	92–119	105.9	20 000	80	0.03	variable > 5
Brown	Pond D-4	18	9	7/16	92–109	99.8	20 000	80	8.6	5
Brown	Pond D-8	20	10	7/16	96–124	110.5	20 000	80	13.2	5
Brown	Pond D-3	20	9	7/16	89–107	98.9	20 000	80	18.7	4
Brown	Pond D-15	20	6	7/16	90–108	99.2	20 000	80	34.7	3
Brown	Pond D-16	20	14	7/16	87–113	103.2	20 000	80	57.4	2
Brown	Pond D-6	20	13	7/17	82–92	85.9	20 000	80	30.1	0
White	Canal	20	15	7/30	26–71	48.6	used to stock ponds			
White	Canal	20	6	7/28	71–112	92.7	used to stock ponds			
White	Pond D-10	15	2	10/15	115–129	122.2	20 000	74	10.5	5
White	Pond D-11	15	12	10/14	103–121	110.1	20 000	73	16.1	5
White	Pond D-12	15	7	10/15	100–114	109.5	20 000	78	24.7	4
White	Pond D-13	16	6	10/14	107–122	112.0	20 000	77	14.3	3
White	Pond D-14	16	9	10/14	111–128	118.3	20 000	78	26.7	2
White	Pond D-1	13	4	10/15	89–99	95.7	20 000	78	10.5	0
Brown	Pond D-1	2	2	10/15	104–112	108.0	—	accidental introduction		
Brown	Hatchery	20	—	6/23	14–21	16.9	used to stock pond A-4 from D-2			
Brown	Pond D-2	15	10	10/16	74–82	78.1	40 000	163	—	—
Brown	Pond A-4	15	9	10/16	84–94	89.3	25 500	163	—	—
Brown	Canal	4	3	10/17	55–69	62.3	used for comparison			

1. The water in the boat basin adjacent to ponds had the following characteristics: 23.5–36.0°C and 8.0–29.8 ppt between 29 April and 16 July and 20–34°C, 16.0–32.1 ppt between 14 July and 23 September.
2. Shrimp dated June and July were fixed when examined and those dated October were fresh.
3. Stocking rate was underestimated.

Table 5. Parasites from penaeid shrimps at Grand Terre, Louisiana, on 26 April 1972[1]

Location	Pond D-13	Pond D-14[2]	Barataria Bay	Barataria Bay
Species of shrimp	Brown	Brown	Brown	White
No. examined	20	15[3]	17	3
No. females	9	8	12	1
No. infected	17	4	16	3
Length of shrimp				
Range	95–118	92–112	73–134	89–95
Average	102.0	104.3	101.1	92.0
Zoothamnium sp. on gills				
Incidence	60	0	82	100
Range	VL-H		VL-H	VL-M
Intensity	1.4		2.2	1.3
Prochristianella penaei				
Incidence	10	0	65	67
Range	2		1–9	6–9
Intensity	2.0		4.1	7.5
Nematopsis penaeus				
Trophozoites				
Incidence	30	0	59	100
Range	1–100		8–200	40–70
Intensity	23.3		70.3	50.0
Gametocysts				
Incidence	55	40	41	67
Range	2–50	1–3	6–40	27–50
Intensity	18.2	2.0	17.4	37.0
Combined incidence	55	40	59	100
Intestinal cestode				
Incidence	0	0	29	33
Range			8–70	10
Intensity			31.6	10.0

1. See footnotes in Table 1 for meaning of headings.
2. Shrimp held overnight in remaining water of draining pond; they were dead or dying in the water containing hydrogen sulfide.
3. Five shrimp from pond D-14 were decaying and only the gills of those were examined.

Additional parasites and commensals not cited in the tables occurred in the Louisiana shrimp. In 1970, a population of 30 white shrimp used to stock the ponds on 14 July had a 10% incidence of the nematode *Leptolaimus* sp. with between one and eight (average 5.0) individuals per shrimp. On 29 April, 38 of 69 brown shrimp had between one and 14 (average 4.9) individuals, mostly in the hepatopancreas. The wild white shrimp also harbored a light infection of *Cephalolobus penaeus*, and the wild brown shrimp had a light infection of the undescribed gregarine.

In 1971, *Zoothamnium* sp. infested the exoskeleton of some of the brown shrimp. All the shrimp in ponds D-2 and A-4 were infested, having an average intensity of 3.7 and 3.0 units, respectively. Those stocks from ponds D-3, D-4, D-5, and D-16 had a few members with more ciliate colonies on the exoskeleton proper than on the gill surface.

Cephalolobus penaeus infected shrimp in ponds D-2 and A-4. All shrimp in A-4 harbored between 6 and 50 gregarines, averaging 22.7 per shrimp. Few shrimp in D-2 were infected with C. *penaeus*, and the only other observation of it at Grand Terre that year was in a single wild white shrimp collected from Barataria Bay on 17 October and not mentioned in Table 3. It also had *Zoothamnium* sp. and *Nematopsis penaeus*.

Leptolaimus sp. was present on the gills of one brown shrimp in pond A-4, and the blue-green alga *Schizothrix calcicola* infested the gills of a few brown shrimp in ponds D-5, D-3, and D-7.

White shrimp in 1971 had few atypical parasites. The most obvious was the presence in either one or two shrimps in ponds D-14, D-13, D-11, D-10, and D-1 of the microsporidean *Thelohania penaei*. The gills of numerous shrimp in those ponds possessed the unidentified fungus and apparently unrelated unidentified brownish pigmented areas within the filaments. The shrimp used to stock the ponds had an infestation of *Zoothamnium* sp. on the exoskeleton similar to that on the gills. *Leptolaimus* sp. was in one shrimp.

In 1972, single infections of *Schizothrix calcicola*, *Nosema nelsoni*, and the fungus occurred in pond-reared brown shrimp. The phycomycete also infected brown shrimp from Barataria Bay, Louisiana, as did the nematode *Thynnascaris* sp.

Brown shrimp from cages in Alabama harbored several organisms in addition to those listed in Table 6. Single shrimp possessed *Schizothrix calcicola*, *Opecoeloides fimbriatus*, *Nematopsis penaeus* (two gametocysts), *Thynnascaris* sp., and a "free-living" nematode on the gills. Several shrimp were fouled with *Obelia bicuspidata* on the eyes, rostrum, and appendages.

Table 6. Parasites from brown shrimp stocked in floating cages on 8–14 June 1971 at Dauphin Island, Alabama, and examined 14–16 July 1971[1]

Location	Length of shrimp					*Zoothamnium* sp. on gills				*Prochristianella penaei*			Intestinal cestode			Incidence with deteriorated chitin on exoskeleton
	Range (mm)	Average (mm)	No. examined	No. females	No. infected	Incidence	Range	Intensity on gills	Intensity elsewhere	Incidence	Range	Intensity	Incidence	Range	Intensity	
Cage 5	56–103	74.7	20	13	19	35	VL-M	1.6	2.4	50	1–2	1.2	55	12–300	119.3	60
Cage 8	58–84	70.9	20	10	18	65	VL-H	2.5	2.6	50	1–2	1.4	35	1–300	147.3	40
Cages 1–4[2]	52–87	71.5	22	9	20	64	VL-H	2.3	3.0	59	1–4	2.2	36	11–180	85.5	14

1. See footnotes in Table 1 for meaning of headings.
2. Data from small numbers of shrimp from each of four cages were similar and therefore combined.

Of the few fixed specimens of pink, brown, and white shrimps sent from Palacios, Texas, all species contained *Thelohania penaei*, and the brown and white shrimps had moderate to heavy infestations of *Zoothamnium* sp. The unusual microsporidean infections were discussed earlier. The sample included two "golden shrimp" and shrimp with signs of chitinoclastic bacteria. Fresh shrimp sent at a different time harbored species of *Vibrio* and *Beneckea*.

Thirteen pink shrimp from Miami ranged between 79 and 96 mm long (averaging 85.5 mm). Eleven shrimp had *Zoothamnium* sp. on the gills with an average relative intensity value of 2.2 units. The gregarines *Nematopsis penaeus* and *Cephalolobus penaeus* each infected one shrimp.

Shrimps infected with microsporideans were sent from Ossabaw Sound, Georgia. The brown shrimp had *Nosema nelsoni* and the white shrimp had both *Thelohania penaei* and *Pleistophora* sp. *Zoothamnium* sp. and *Nematopsis penaeus* infected both species. The white shrimp contained numerous specimens of *Opecoeloides fimbriatus* attached to ovarian tissue.

Observations on the diet of white and brown shrimps revealed a wide variety of items such as benthic and planktonic copepods, amphipods, rotifers, polychaetes, gastropods, algae, plant detritus, and commercial feed.

Discussion

Zoothamnium sp., without question, was the most common organism infecting pond-reared hosts and was found on shrimp from all areas examined. It appeared to be involved with mortalities of pond-reared shrimp in both Louisiana and Texas and will be discussed in greater detail later in this report.

Microsporideans did not appreciably influence the harvest in any of the ponds, but infections originating in ponds could drastically hamper useful production. Since the incidence of *Thelohania penaei* was uniformly low in ponds with white shrimp and since the ponds were stocked with wild juvenile shrimp, I believe the infections were present in shrimp during stocking. Davidson Neal (personal communication) informed me that a few infected juveniles were culled before stocking. None of the brown shrimp reared from eggs had microsporidiosis. As mentioned earlier, the life cycle of none of the microsporideans in shrimp is known, but a high incidence of infection does not seem impossible, especially if an infected shrimp is introduced and dies.

Prochristianella penaeid infected pink shrimp in ponds in Florida (Villella et al., 1970). These shrimp had been reared from eggs, as opposed to most of the shrimp used in the present study which were captured when young from Barataria Bay. Most of the data in Tables 1, 3, and 5 suggest that the stocking population was infected and no further infections took place. The incidence and intensity of *P. penaei* in pond-reared white shrimp in 1970 and 1971 was similar in the different ponds, similar with infections in shrimp used to stock the ponds, and less than found in large wild white shrimp in adjacent water. In contrast, no larvae were found in brown shrimp used to stock ponds in 1970 but were present in the harvested hosts. Only one pond of brown shrimp in 1971 was infected, and the intake filter in that pond, D-16, might have had a hole and permitted infectious organisms to enter

the pond. No larvae infected brown shrimp reared from eggs in 1971 (Table 3), and Tables 1 and 5 reveal higher rates of incidence and heavier infections in natural populations than in reared ones. An increase in intensity with length of shrimp in wild hosts in Mississippi observed by me and in Texas and Louisiana by Aldrich (1965) and Ragan and Aldrich (1972) suggested the shrimp continually acquire new larvae. Brown shrimp are usually more heavily infected than white shrimp.

Since infections may occur in ponds, the matter of how they occur is important. Kruse (1959), Aldrich (1965), Villella et al. (1970), and Ragan and Aldrich (1972) all assumed that the shrimp acted as a second intermediate host requiring an additional host such as a copepod. A recent study on postembryonic development of *Parachristianella monomegacantha* Kruse, 1959 by Mudry and Dailey (1971), however, suggested that cestodes, such as *Prochristianella penaei*, which parasitize nonpiscivorous elasmobranchs, used only a single crustacean host. The authors experimentally infected the copepod *Tigriopus californicus* (Baker) with infective oncospheres of *P. monomegacantha* still in the eggs, rather than with coracidia, which are found in three-host life cycles. Eggs for that study were obtained from the shovelnose guitarfish, *Rhinobatos productus* (Ayres).

Infection by *Nematopsis penaeus* is common and typically occurs in ponds, as suggested by both this study and that of Villella et al. (1970). A discussion about the possibility of more than one species and on the life history of a related species appears in the section on common parasites.

Considerable variation in the incidence and intensity of infections in the various ponds for both trophozoites and gametocysts suggests that conditions in individual ponds differ, allowing differences in the availability of infective organisms. All the ponds in 1970 were infected except one, and that, pond D-11, was overgrown with vegetative material. In 1971, the incidence of infection differed greatly from that in the previous year. Brown shrimp in only one pond in July were infected and not with trophozoites. All the ponds with white shrimp were infected but two, one of those being D-11 again. Brown shrimp reared from eggs better reflect the importance of a proper environment for the infection to occur and that infections are acquired in the ponds. No hatchery-reared shrimp in pond D-2 on 23 June, 1971 were infected when several were removed to stock pond A-4. On 16 October, 73% of 15 of the transferred shrimp harbored an average of 39 trophozoites, with 33% containing an average of 80 gametocysts in the rectum compared to an average of six in half of the wild brown shrimp in adjacent waters. The shrimp in pond D-2 remained uninfected.

To further elaborate the need for proper substrata, only one of 62 brown shrimp examined from floating cages continuously suspended from the muddy, sandy bottom (Table 6) was infected, and it had two gametocysts. Presumably many of the caged shrimp lost earlier infections. Kruse (1966a, 1966b) observed that planktonic postlarval shrimps were uninfected until they became benthic organisms on inshore nursery grounds.

Brown shrimp from pond D-14 in 1972 were examined at the time of harvesting. The exhaust standpipe became clogged during the night and anaerobic sediments were disrupted by personnel walking in the pond. The water became contaminated and the smell of hydrogen sulfide offensive. Most of the shrimp were dead, but the few dying individuals were examined. Comparative data in Table 5 between shrimp in two similarly stocked

ponds, D-13 and D-14, suggest the unfavorable condition of the water in pond D-14 might have killed or caused shrimp to rid themselves of infections with *Zoothamnium* sp. and *Nematopsis penaeus*. Probably *Prochristianella penaei*, rare in pond D-13, would have been observed in shrimp from pond D-14 if additional shrimp could have been examined.

With the exception of one white shrimp in pond D-1 in 1970 (Table 3), no other ponds at Grand Terre contained the intestinal larval cestode. Since brown shrimp were common in the pond and the number of *Prochristianella penaei* per shrimp was higher than in other ponds, there is a possibility the pond was contaminated with unfiltered water from the adjacent canal. The intestinal cestodes were prevalent in wild shrimp in adjacent water in both 1971 and 1972 and also in shrimp maintained in cages in Alabama. The cestodes were probably acquired when the shrimp in cages fed on passing copepods or some planktonic animal.

Growth of the blue-green alga *Schizothrix calcicola* and the phycomycete on the gills was never associated with mortalities or unhealthy appearing shrimp at Grand Terre, even though several hosts were heavily infested. Presumably, the water quality could be altered in such a way that these organisms could become an important component related to health of the hosts.

The most conspicuous observations on the brown shrimp examined from cages in Alabama were the short body lengths, the heavy growth of external organisms, and the deteriorated chitin of the exoskeleton. The eyes, appendages, and carapace were more heavily infested with *Zoothamnium* sp. than the gills, and *Obelia bicuspidata* covered considerable areas on some individuals. During ecdysis, brown shrimp use a muddy, sandy substratum for feeding, burrowing, and protection from predators, including other shrimp. Deprivation of this type of bottom, in addition to a probable insufficiency of food, apparently caused the shrimp to molt infrequently and subsequently accumulate considerable epizoic growth. Probably nonmolting shrimp had a much better chance of survival. Many shrimp directly from the cages exhibited excessive pigmentation and soft musculature. Shrimp maintained in containers for several days molted and lost external growths.

Walter Tatum (personal communication) concluded that it was impractical to use cages to rear shrimp. By the time of harvest on 16 August 1971, few of the original 1000–2000 shrimp per cage had doubled in length. Mortality ranged between 86% and 95% of the shrimp in the examined cages, presumably from cannibalism, and the total final weight was less than the total initial weight.

Effects of Parasites

A parasite by definition lives at the expense of the host, but it should be stressed that some organisms associated with shrimp are commensal and do not harm the host. It would be impractical for a parasite to destroy its host population, since it would essentially destroy itself. But some parasites do severely harm their hosts. In some cases, this could result in the remaining shrimp acting as a superior breeding stock to better the population in the long run. Also, a parasite which is pathogenic to one species and not another may be poorly adapted to the former which was recently introduced into the life cycle of the parasite. In contrast, it can be beneficial for a parasite to weaken or kill an individual host. If larval

stages of helminths weaken a host so that the host is more vulnerable to predation by the definitive host for the parasite, the worm prospers and more readily completes its life cycle.

Most important, some organisms become pathogenic when hosts are crowded together or otherwise stressed, as is the situation in rearing facilities for shrimps or other animals. Some of these organisms have more effect on shrimp and the marketable product than others. Microsporideans in large shrimp cause inedible or, at best, a poor quality product. Infected shrimp used for bait usually die more easily than noninfected ones when under stress. The relatively large percentage of shrimp containing *Nosema nelsoni*, *Pleistophora* sp., or *Thelohania penaei* from estuaries in Mississippi during periods when similar sized shrimp of the same species have mostly moved out of the nursery grounds suggests that the sporozoans have an influence on the shrimps' migratory behavior. Apparently this is partially also true in reverse. When there are few large white shrimp left in fishing areas of Mississippi and Louisiana, shrimp fishermen note a higher than normal percentage of shrimp infected with *T. penaei*. Joyce (1965) collected "milk" white shrimp only from densely populated nursery areas in northeastern Florida but mentioned that shrimpers had seen them offshore.

The effect of microsporideans on small shrimp is unknown but could cause extensive mortalities. *Thelohania penaei* does cause castration in adult white shrimp. To my knowledge, no ponds have ever had a large-scale infection originating from within the system, with the possible exception of a high incidence of a microsporidean infecting brown shrimp reared at Grand Terre in the late fall of 1968 cited by Broom (1968). The shrimp died, and Broom did not know if the disease or unfavorable weather conditions caused the mortalities.

Ciliates infesting gills do not appear to affect growth in large shrimp but could have a synergistic effect during periods of stress or could be serious pathogens to young shrimp. I have seen them on postlarval shrimp in Mississippi. In a note by Johnson (1972), mortality of brown and white shrimps reared in Brazoria and Orange Counties in Texas was considered a consequence of the presence of heavy infestations of *Zoothamnium* sp. (= *Epistylis* sp.) Johnson et al. (in press) later attributed the deaths to heavy infestations when the level of dissolved oxygen in the ponds dropped to 2.6 ppm and, in addition, considered 25 ppm of formalin to be an effective controlling agent. Fouling organisms, less specific to shrimp than the encountered ciliates, can probably be equally destructive to shrimp that do not molt regularly.

Ragan and Aldrich (1972) found no relationship with incidence of *Prochristianella penaei* and the length-weight relationship of relatively large brown or white shrimps, and Martosubroto (1972), working with pink shrimp, did not think "*Contracaecum* sp." within the ovary and *Prochristianella* sp. encysted in the ovarian wall had a pronounced effect on fecundity. I have never observed any obvious tendency for any macroscopic parasites to affect growth in maturing shrimp. Corkern (1970) reported statistically different slopes for length of carapace of brown shrimp versus both weight of body and weight of hepatopancreas in samples of shrimp that died early in an experiment compared with those shrimp that did not die early and those that lived the entire nine weeks of captivity. He, however, could not relate those differences to different levels of helminthic infections.

Adventitious organisms such as bacteria and fungi are almost always associated with shrimp, but not until shrimp are crowded into unnatural habitats are the hosts especially vulnerable to diseases caused by the various organisms. One such disease, "shell disease," is conspicuously notable in reared shrimp because of the deteriorated exoskeleton. This condition, possibly a "catch basket" for several diseases caused by numerous organisms, has already been proven to be an economically serious problem when maintaining lobsters (see review by Rosen, 1970) and is a potential problem for all reared crustaceans. The soft tissues underlying the exoskeleton apparently do not become infected, but in the lobster, at least, the gill membranes are known to become diseased, and the rate of mortality of diseased hosts is high.

Little is known about pathological effects of parasites and diseases on young shrimp. Parasites that cause little or no apparent harm to adult animals can cause mortality in young stages. Rosenthal (1967) showed that two internal and two external parasitic species, which are not serious pathogens in adults, produced about a 10% rate of mortality in larval herring reared in aquaria and fed wild plankton. Presumably, parasites of shrimp such as *Zoothamnium* sp., *Thynnascaris* sp., *Prochristianella penaei*, *Parachristianella dimegacantha*, *Opecoeloides fimbriatus*, and the different microsporideans could cause substantial mortalities in young shrimp. Possibly the most serious threat to young shrimp are fungal infections. Those persons rearing larval crustaceans either on a large or small scale commonly lose many of their animals to fungal or bacterial infection.

Relationship between Stress and *Zoothamnium* sp.

An increase in intensity of infestation with *Zoothamnium* sp. with an increase in stocking density of pond-reared brown shrimp during 1970 suggests a relationship between the two. Mortality rates, attributed by fisheries biologists to observed low dissolved oxygen concentrations, were high in ponds stocked in excess of 5000 shrimp per pond (20 000 per acre). In order to examine the relationship between the rate of intensity of the ciliate and the predilection to mortality following a short period of stress caused by crowding and oxygen depletion, a simple experiment was conducted. A population of brown shrimp containing some individuals with heavy infestations was collected with a small otter trawl towed for five-min periods and purposefully crowded into a half-filled 0.09 m^3 aerated container. Upon return to the laboratory, the dead shrimp were removed, the oxygen concentration measured, and the aeration removed. After 45–90 min, when the level dropped from 4 to 8 ppm to between 2.3 and 0.6 ppm and several shrimp began to die, the aeration was returned and dead individuals removed. All the gills on one side of each shrimp were examined and the infestations valued as before. Computed and listed in Table 7 were the mean values for the three groups: those dead at arrival, those dead after stress, and those that survived. The mean values for those dead after being stressed in four replications were all greater than those for the other groups, with the surviving shrimp having the lowest mean values.

Table 7. Mean relative values indicating the intensity of infestation with *Zoothamnium* sp. on the gills of experimentally stressed brown shrimp

	Sample size (*n*) and replication number							
	n	1	*n*	2	*n*	3	*n*	4
Death before experiment	12	2.25	9	2.44	28	1.82	0	
Death after oxygen depletion	31	2.77	14	2.50	13	2.00	20	2.45
Survivors	20	1.60	28	2.00	13	1.46	44	2.27

The initially dead and surviving individuals were then separately compared with those that died after the oxygen was removed, using a chi-square test. The numbers of shrimps in each of the five different groups valued by intensity, including individuals not infected, were compared and the values listed in Table 8. Only the chi-square value from replicate 4 indicates that the shrimp more heavily infested with ciliates are more likely to die when confronted with a short period of severe stress. This relationship loses its significance after applying a Yate's correction factor for small samples.

Table 8. Chi-square values[1] for the relationship between survival and death in stressed shrimp with five different rates of infestation with *Zoothamnium* sp.

	Experiment number			
	1	2	3	4
Death after stress/ survivors	2.92	1.74	3.38	—
Death before experiment/survivors	8.13 (4.99)[2]	2.72	2.45	12.38 (9.23)[2]
Total no. of shrimp before experiment	63	51	54	64
Total no. of shrimp in experiment	51	42	26	64

1. In a one tailed test with four degrees of freedom $P < 0.25 = 7.78$, $P < 0.05 = 11.1$.
2. Value computed using a Yate's correction factor for small samples.

Discussion

The mean values of infestation with *Zoothamnium* sp. in the shrimp surviving a short term of stress are less than those of dead shrimp, suggesting the rate of infestation influences survival. A closer analysis of the data, however, does not support this. The fourth replication, the one that indicated a relationship, differed from the earlier three in that shrimp were maintained in two containers before the experiment was started, and, consequently, there were no initial deaths. Also, the ctenophores *Mnemiopsis mccradyi* and *Beroe ovata* clogged the trawl to a greater degree in the first three replicates, certainly causing stress of a different nature.

Whether the ciliates remove a significant amount of oxygen when the oxygen tension is already low, mechanically prevent gas diffusion across the gill membrane, cause pathological responses, or have no effect on the shrimp remains to be shown. The experiment indicates a need for additional study. Possibly the length or age of shrimp contributes to the results. The average length of the experimental shrimp was 106.4 mm, but those that died after being stressed ranged between 1.2 and 10.7 mm larger. The difference in the fourth replicate was the largest. To add to the confusion, high infestations in wild populations

often occur in low saline water, and shrimp maintained in the laboratory for a day or so usually molt and lose the infestation. In any event, if a relationship exists between mortality and stressed infested shrimp, a relationship also suggested by Johnson et al. (in press), it is probably complex.

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